Optimization of Impedance Bandwidth of a Stacked Microstrip Patch Antenna with the Shape of Parasitic Patch's Slots

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Abstract ─ In this paper, a novel configuration of wideband stacked microstrip antenna for X/Ku band is presented and analyzed. By cutting five narrow rectangular and one trapezoidal slot on parasitic patch with different dimensions, the impedance bandwidth and resonance frequency of the proposed antenna is adjusted. Also, the effect of incorporated parallel slots on driven patch is examined based on equivalent circuit of E-shaped microstrip antenna. Antenna characteristics are simulated by CST simulator and far-field radiation patterns of simulated and measured results of an array of the proposed antenna are compared.

Index Terms ─ Equivalent circuit, stacked microstrip antenna, X/Ku band.

I. INTRODUCTION

Low gain, narrow bandwidth and low efficiency are confined microstrip antenna's applications beside their attractive features such as low weight, small size and ease of integration with microwave integrated circuits (MIC) [1].

Suffering from very narrow bandwidth poses efforts to design wideband microstrip antennas. Different methods like cutting slots in microstrip patch antenna [2] and stacking [3] have been reported to enhance the bandwidth of microstrip antennas. Impedance mismatch is reduced by a slot which is cut in microstrip patch antenna. In that way, the bandwidth increases. Also, by using multilayered substrates in microstrip antennas, degree of freedom to optimize antenna's performance characteristics such as bandwidth and gain increases [4].

Based on these approaches, the stacked microstrip antennas have appeared. In these structures, commonly two conducting patches are used in each layer. The bottom patch as a driven patch is excited by a coaxial probe and the upper patch is a parasitic patch [5].

In many reports such as [6] and [7], E-shaped rectangular patch antenna is used as the driven patch in stacked microstrip antennas. By referring to [8], an E-shaped rectangular patch is known as a wideband antenna due to two parallel slots cut into the rectangular patch. So, this antenna can be a proper driven patch to enhance stacked microstrip bandwidth.

In this paper, the E-shaped rectangular patch antenna is chosen as a driven patch. Contrast to common stacked antennas which have a simple rectangular patch as a parasitic patch, in this paper, a rectangular patch with six slits that have different lengths and widths. Also, one trapezoidal slot is cut in parasitic patch. This kind of parasitic patch can add different poles to antennas return loss. In fact, by inserting different slots with different dimensions and shapes in parasitic patch, the bandwidth of stacked antennas can be adjusted and the resonance bandwidth of them can be shifted to expected frequencies based on equivalent circuit of proposed antennas.

According to several applications for X/Ku band such as vehicle tracking, weather forecasting radars, dimensions of driven and parasitic patches are optimized to work in X/Ku band. The proposed antenna is simulated in CST and simulated results are compared with measurement.

II. ANTENNA DESIGN AND THEORETICAL CONSIDERATIONS

The geometry of the proposed antenna is presented in Fig. 1. In the present work, the patch is fed by co-axial cable (50 ohm). As shown in Fig. 1, the E- shaped patch is printed on the lower substrate as the driven patch. Dimensions of such patch are optimized to work in X/Ku band. Based on [9], the equivalent circuit of E-shaped is illustrated in Fig. 2. It can be seen, ΔC which is added due to two parallel slots, plays the main role in changing

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the input impedance according to the equation 1, 2 and 3, which is modified based on small value of ΔC.

In [9], the ΔC is given by:

$$Zin = \frac{1}{R + j\omega L_2 + \frac{1}{j\omega C_2}}, \tag{1}$$

$$C_2 = \frac{\Delta C.C_1}{\Delta C + C_1} \approx \Delta C, \tag{2}$$

$$\Delta C = 2l_2 \frac{\varepsilon_0}{\pi}\left[\ln\left(2\frac{1+\sqrt{k'}}{1-\sqrt{k'}}\right)\right] + \ln\coth\left(\frac{\pi w_2}{4h_2}\right) + 0.013\frac{h_2}{w_2}, \tag{3}$$

where

$$k' = \sqrt{1-k^2}, \tag{4}$$

$$k^2 = \frac{\left(\frac{2(2w_2 + wf)}{w_2} - 1\right)}{\left(1 + \frac{2w_2 + wf}{w_2}\right)\left(\frac{wf}{w_2}\right)}. \tag{5}$$

In equation (3), the length of etched slots along a resonance edge has the main parameter to calculate. So, by varying l_2 and w_2, the input impedance can be controlled. To determine E-shaped antenna's dimensions, at the first step based on [1], the length and width of a rectangular patch are calculated for resonation in desire frequency. The length and width of E-shaped microstrip patch antenna are chosen same as the length and width of a rectangular patch:

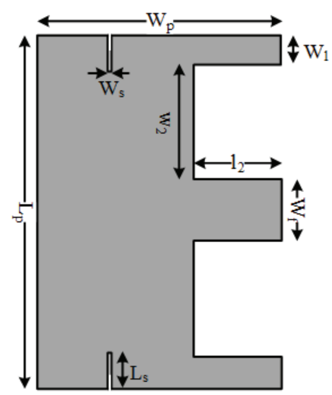
$$L_P = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r + 1}{2}}}, \tag{6}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h_1}{L_P}]^{-1/2}, \tag{7}$$

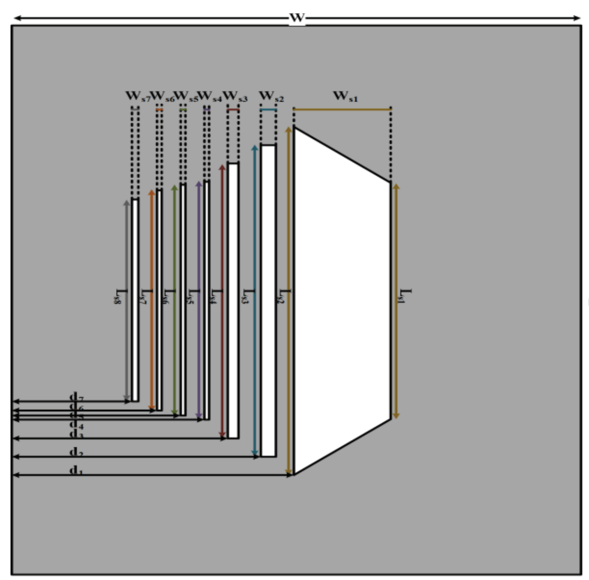
$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}}, \tag{8}$$

$$\Delta L = 0.421h\frac{(\varepsilon_{reff} + 0.3)(\frac{L_P}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{L_P}{h} + 0.8)}. \tag{9}$$

In the next step, the amount of C_1 and L_1 which is shown in Fig. 2, are calculated based on [1]. ΔC should be around 100 times smaller than C_1 to satisfy the equation (2). According to this point, l_2 and w_2 are estimated. As the result of this analysis, the impedance bandwidth can be adjusted based on equation (1). To improve VSWR, two slits are etched along non resonance edges. In the next step, to enhance the impedance bandwidth, a wideband structure is chosen as the parasitic patch which is located on top layer. A rectangular patch with seven slots is selected to improve band width. According to different lengths and widths of these slots, the band width of the antenna can control and widens up to 23%. Also, different shapes of such slots have impressive effect on VSWR due to the alternation that is accrued in equivalent circuit of the stacked antenna based on [10]. Dimensions of the proposed stacked antenna are mentioned in Table 1. The thickness of lower layer (h_2) and top layer (h_1) are 1.65 mm and RO4003 is chosen as the substrate for both layers in demonstrated structure.



(a)



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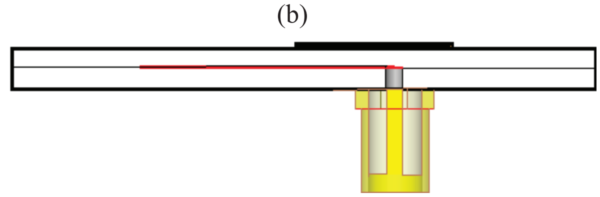


(c)

Fig. 1. (a) E-shaped microstrip antenna as the driven patch in lower layer, (b) rectangular microstrip antenna with six rectangular slits and a trapezoidal slot as the parasitic patch in the top layer, and (c) side view of the proposed stacked antenna.

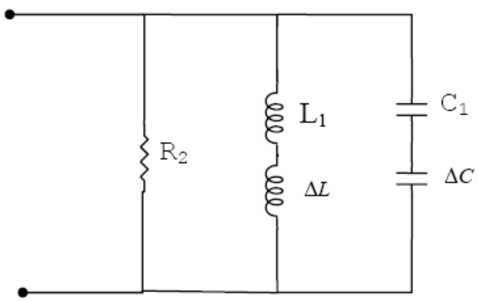


Fig. 2. Equivalent circuit of the E-shaped patch antenna.

Table 1: Dimensions of the proposed stacked microstrip antenna

Parameters	Dimensions (mm)
Wp	20
Lp	30
Ws	0.3
W_1	2.5
W_2	10
l_2	7.5
W_f	5
L_s	3
L	15
W	12
Ls1	6.5
Ls2	9.5
Ws1	2
Ls3	8.5
Ws2	0.3
Ls4	7.5
Ws3	0.2
Ls5	6.5
Ws4	0.1
Ls6	6.3
Ws5	0.1
Ls7	6
Ws6	0.1
Ws7	0.1
Ls8	5.5
d_1	6
d_2	5.3
d_3	4.6
d_4	4.1
d_5	3.6
d_6	3.1
d_7	2.6

In this paper, to design antenna which its center frequency is 12 GHz, the calculated length is 18.3 mm. This dimension causes C_1 to become around 1 pF. In that way, by choosing ΔC~0.01 pF, the dimensions of parallel slots on E-shaped antenna is calculated based on equation (3).

III. RESULTS AND DISCUSSION

Variation of S_{11} with different values of l_2 is shown in Fig. 3. As illustrated in Fig. 3, l_2 as the length of the etched slots along a resonance edge on driven patch, has the significant impact on shifting resonance frequency. By increasing l_2, the resonance frequency decreases due to increase in electrical length of slots on driven patch.

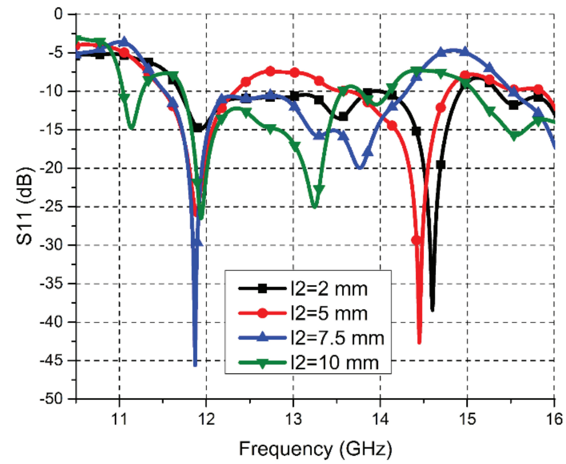


Fig. 3. Variation of S_{11} with different values of l_2.

By adding parasitic patch on E-shaped microstrip antenna, mutual capacitance is added to equivalent circuit of the proposed antenna [12]. Based on [13], this mutual capacitance's value depends on top layer thickness. Variation of reflection coefficient with upper layer thickness is simulated and shown in Fig. 4. By increasing the upper layer thickness, mismatch of the antenna decreases in wide range of frequencies. In that way, the impedance bandwidth will enhance dramatically. This extend in the impedance bandwidth, is the result of the decrease in the mutual capacitance which is created between driven and parasitic patches [11].

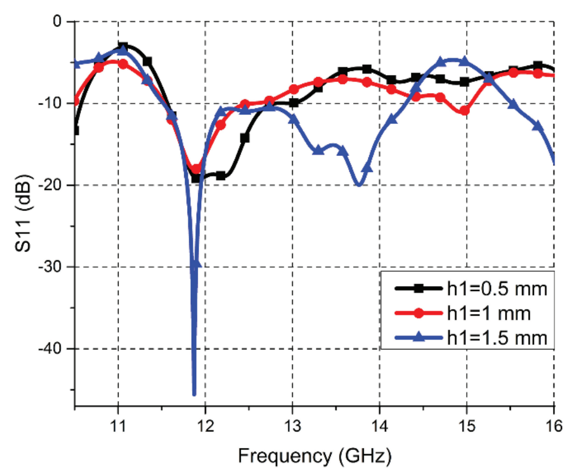


Fig. 4. Variation of S_{11} with upper layer thickness.

Finally, to improve antenna's gain, the stacked structure is used as the element of an array. To confirm this, far field pattern of single and array structures are compared in Fig. 5.

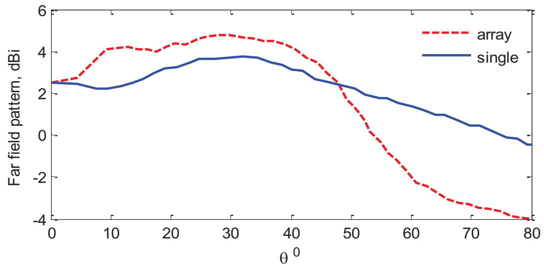
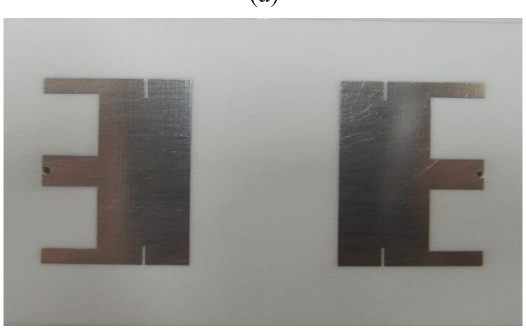


Fig. 5. Far field pattern of the proposed single and array antenna.

By considering the plane of the antenna is theta=90°, for specific application that antenna's gain should be improved between phi=0° and phi=30°, the proposed antenna has the better gain as the array structure with 29.2 mm distances between two elements.

For the fabricated array antenna which is shown in Fig. 6, array's gain of simulation and measurement of the representative structure are shown in Fig. 7. It can be seen that the simulated and the measured results are in a good agreement. As can be seen in Fig. 7, the main lobe of the proposed antenna is around φ=70° at the plane θ=90°.

(a)



(b)

Fig. 6. (a) The parasitic patch of proposed antenna, and (b) the driven patch of proposed antenna.

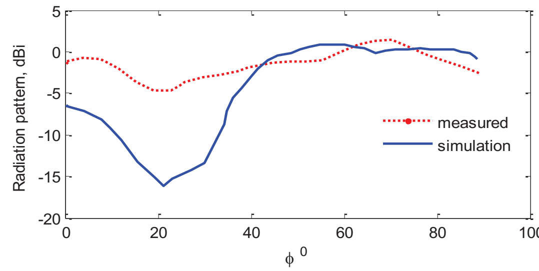


Fig. 7. Antenna far-field radiation pattern at θ=90°.

IV. CONCLUSION

A novel design of wideband stacked microstrip antenna has been constructed by cutting six different slots with different areas on parasitic patch. This modification on parasitic patch antenna shape, enhanced the bandwidth of the microstrip antenna up to 23%, which shows improvement in comparison with the recent existing data [14]. Based on the equivalent circuit of E-shaped microstrip antenna, the frequency band that antenna works is adjusted. To improve antenna gain, the proposed antenna has been used as the element of an array. The far-field radiation patterns of simulated and measured results are compared, which shows acceptable agreement.

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